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DESCRIPTION

THERMOACOUSTIC APPARATUS AND THERMOACOUSTIC SYSTEM

Technical Field

[0001] The present invention relates to a thermoacoustic apparatus capable of cooling or heating an object through the use of thermoacoustic effect and a thermoacoustic system including the thermoacoustic apparatus.

Background Art

[0002] Known technologies of a heat exchanger through the use of thermoacoustic effect include the technologies described in the following Patent Document 1, Non-Patent Document 1, and the like.

[0003] The apparatus described in Patent Document 1 relates to a cooling apparatus through the use of thermoacoustic effect. This apparatus is configured to include a first stack sandwiched between a high-temperature-side heat exchanger and a low-temperature-side heat exchanger and a regenerator sandwiched between a high-temperature-side heat exchanger and a low-temperature-side heat exchanger in the inside of a loop tube, in which a working fluid is enclosed, where an acoustic wave is generated through self excitation by heating the high-temperature-side heat exchanger on the first stack side, and

the low-temperature-side heat exchanger on the regenerator side is cooled by a standing wave and a traveling wave based on the acoustic wave.

[0004] Likewise, Non-Patent Document 1 discloses an experimental study of a cooling apparatus through the use of thermoacoustic effect. The cooling apparatus used in this experiment is also configured to include a substantially rectangular cross-section loop tube formed from a metal, a first stack sandwiched between a heater (high-temperature-side heat exchanger) and a low-temperature-side heat exchanger, and a second stack disposed at a position opposite to the first stack. A temperature gradient is generated in the first stack by heating the heater (high-temperature-side heat exchanger) disposed on the first stack side and, in addition, circulating running water in the low-temperature-side heat exchanger, and an acoustic wave is generated through self excitation in a direction opposite to the temperature gradient. The resulting acoustic energy is transferred to the regenerator side through the loop tube, and on the second stack side, thermal energy is transferred in the direction opposite to the direction of the acoustic energy on the basis of the energy conservation law, so as to cool the vicinity of a thermometer on the other end side of the second stack. According to this document, a temperature reduction of about 16°C has been ascertained under a

predetermined condition at the portion where the thermometer has been disposed.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2000-88378

Non-Patent Document 1: Shinichi SAKAMOTO, Kazuhiro MURAKAMI, and Yoshiaki WATANABE, "Netsuonkyou Koukao Mochiita Onkyoureikyaku Genshouno Jikkenteki Kentou (Experimental Study of Acoustic Cooling Phenomenon Through the Use of Thermoacoustic Effect)", The Institute of Electronics, Information and Communication Engineers, TECHNICAL REPORT OF IEICE. US2002-118 (2003-02)

Disclosure of Invention

Problems to be Solved by the Invention

[0005] In the apparatus through the use of the above-described thermoacoustic effect, the time period from heating to generation of the standing wave and the traveling wave must be reduced. Furthermore, after the standing wave and the traveling wave are generated, the efficiency of heat exchange must be improved. In the case where the standing wave and the traveling wave are generated rapidly, it is necessary that, for example, the temperature gradient is formed in the stack as rapid as possible and the surface wavefront of the generated acoustic wave is stabilized as rapid as possible.

[0006] However, in the above-described Patent Document 1, since the first stack serving as a generation source of an acoustic wave is disposed in a horizontal linear tube portion relative to the ground, the heat input into the high-temperature-side heat exchanger of the first stack spreads in a horizontal direction in the linear tube portion and, therefore, the heat enters the first stack, so that a large temperature gradient cannot be generated in the stack. Consequently, it takes much time until an acoustic wave is generated through self excitation, and there is a problem in that the cooling efficiency cannot be improved. In order to generate the standing wave and the traveling wave rapidly, it is necessary to stabilize the surface wavefront of the acoustic wave generated in the first stack as rapid as possible. However, if the distance from the first stack to the corner portion of the loop tube is small, the surface wavefront before being stabilized is reflected at the corner portion of the loop tube, the surface wavefront is disturbed, and there is a problem in that it takes much time until an acoustic wave is generated through self excitation.

[0007] Accordingly, in order to overcome the above-described problems, it is an object of the present invention to provide a thermoacoustic apparatus including a loop tube, wherein a standing wave and a traveling wave are generated rapidly and, thereby, heat exchange is performed rapidly and

efficiently.

Means for Solving the Problems

[0008] In order to overcome the above-described problems, a thermoacoustic apparatus according to an aspect of the present invention includes a first stack sandwiched between a first high-temperature-side heat exchanger and a first low-temperature-side heat exchanger and a second stack sandwiched between a second high-temperature-side heat exchanger and a second low-temperature-side heat exchanger in the inside of a loop tube, wherein a standing wave and a traveling wave are generated through self excitation by heating the above-described first high-temperature-side heat exchanger, the above-described second low-temperature-side heat exchanger is cooled by the standing wave and the traveling wave, or/and a standing wave and a traveling wave are generated through self excitation by cooling the above-described first low-temperature-side heat exchanger, and the above-described second high-temperature-side heat exchanger is heated by the standing wave and the traveling wave, and in the thermoacoustic apparatus, the above-described loop tube is configured to include a plurality of linear tube portions, which stand relative to the ground, and connection tube portions shorter than the linear tube portions, and the above-described first stack is disposed in the longest

linear tube portion among the plurality of linear tube portions.

[0009] According to this configuration, the surface wavefront of the acoustic wave generated in the first stack can be stabilized in the linear tube portion set to be the longest, and the standing wave and the traveling wave can be generated rapidly. Since the first stack is disposed in the linear tube portion standing relative to the ground, the time until the acoustic wave is generated can be reduced through the use of an updraft or a downdraft generated on the first stack side. Furthermore, after the standing wave and the traveling wave are generated, the efficiency of heat exchange can be improved.

[0010] When the lengths of the linear tube portion and the connection tube portion of the above-described loop tube are assumed to be La and Lb, respectively, the lengths are set in such a way as to satisfy $1:0.01 \leq La:Lb < 1:1$.

[0011] According to this configuration, since the linear tube portion becomes relatively long, as in the above description, the surface wavefront of the acoustic wave can be stabilized. It is preferable that the linear tube portion is as long as possible, and when the lengths are set in such a way as to satisfy $La:Lb \leq 1:0.5$, the surface wavefront of the generated acoustic wave can be further stabilized.

[0012] In the above-described apparatus, in the case where the first high-temperature-side heat exchanger is heated and the second low-temperature-side heat exchanger is cooled, the first stack is disposed below the center of the linear tube portion.

[0013] According to this configuration, a large space for generation of an updraft due to the heat applied to the first high-temperature-side heat exchanger can be ensured in the upside, and the standing wave and the traveling wave can be generated rapidly through the use of the updraft.

[0014] Moreover, in the case where the first low-temperature-side heat exchanger is cooled and the second high-temperature-side heat exchanger is heated, the first stack is disposed above the center of the linear tube portion.

[0015] According to this configuration, a large space for generation of a downdraft due to the heat at a low temperature (hereafter referred to as "low-temperature heat") applied to the first low-temperature-side heat exchanger can be ensured in the downside, and the standing wave and the traveling wave can be generated rapidly through the use of the downdraft.

[0016] When one end of the linear tube portion is connected to one end of the connection tube portion, an intersection of the respective center axes is assumed to be

a start point of a circuit, and an entire length of the circuit is assumed to be 1.00, the center of the first stack is set at a position corresponding to 0.28 ± 0.05 relative to the entire length of the circuit.

[0017] According to this configuration, when the respective temperatures of the first high-temperature-side heat exchanger and the first low-temperature-side heat exchanger in the first stack are appropriate, the acoustic wave can be generated through self excitation more rapidly.

[0018] When an entire length of the circuit is assumed to be 1.00, a first peak of the pressure variation of a working fluid along the circuit is present in the vicinity of the first stack, and a second peak is present at a position corresponding to about one-half the entire length of the circuit, the above-described second stack is disposed in such a way that the center of the second stack is positioned past the above-described second peak.

[0019] According to this configuration, the cooling efficiency or the heating efficiency in the second stack can be increased.

[0020] An acoustic wave generator for generating the standing wave and the traveling wave is disposed on the outer perimeter portion or in the inside of the loop tube.

[0021] According to this configuration, the standing wave and the traveling wave can be generated more rapidly not

only by the acoustic wave through self excitation, but also by forced vibration from the acoustic wave generator.

[0022] The first stack or/and the second stack to be used include connection channels arranged in such a way that the inner diameters of individual connection channels are increased one after another as the position of the connection channel approaches the outside.

[0023] When such a stack is used, since the inner diameters of the connection channels in the vicinity of the boundary layer in the inside of the loop tube can be increased, the energy exchange in this portion can be performed efficiently.

[0024] Alternatively, the first stack or/and the second stack to be used include connection channels arranged in such a way that the inner diameters of individual connection channels are decreased one after another as the position of the connection channel approaches the outside.

[0025] When such a stack is used, since the inner diameters of the connection channels in the center portion in the inside of the loop tube can be increased, the energy exchange in this center portion can be performed efficiently.

[0026] Alternatively, the first stack or/and the second stack to be used include meandering connection channels.

[0027] When such a stack is used, since large surface areas of the working fluid and the stack can be ensured, the

heat exchange with the working fluid is facilitated and, thereby, higher-temperature heat can be output.

[0028] Alternatively, the first stack or/and the second stack to be used include connection channels arranged in such a way that the flow path lengths of individual connection channels are decreased one after another as the position of the connection channel approaches the outside.

[0029] When such a stack is used, the flow path lengths of connection channels close to the boundary layer of the loop tube are decreased, the speed gradient can be made uniform and, thereby, the heat exchanger can be heated or cooled uniformly.

[0030] The thermoacoustic apparatus according to an aspect of the invention, in which a material for the first stack or/and the second stack is composed of at least one type of ceramic, sintered metal, gauze, and nonwoven metal fabric, and the $\omega\tau$ (ω: an angular frequency of the working fluid, τ: temperature relaxation time) thereof is configured to become within the range of 0.2 to 20.

[0031] According to this configuration, an acoustic wave can be generated through self excitation more rapidly and efficiently.

[0032] Furthermore, a plurality of the above-described thermoacoustic apparatuses are disposed, wherein a second low-temperature-side heat exchanger in one thermoacoustic

apparatus is connected to a first low-temperature-side heat exchanger in another thermoacoustic apparatus adjacent thereto, or a second high-temperature-side heat exchanger in one thermoacoustic apparatus is connected to a first high-temperature-side heat exchanger in another thermoacoustic apparatus adjacent thereto.

[0033] According to this configuration, since the temperature gradient in the first stack is increased one after another on an adjacent thermoacoustic apparatus basis, higher-temperature heat or lower-temperature heat can be output from the thermoacoustic apparatus on the end side.

Advantages

[0034] The thermoacoustic apparatus according to an aspect of the present invention includes the first stack sandwiched between the first high-temperature-side heat exchanger and the first low-temperature-side heat exchanger and the second stack sandwiched between the second high-temperature-side heat exchanger and the second low-temperature-side heat exchanger in the inside of the loop tube, wherein a standing wave and a traveling wave are generated through self excitation by heating the above-described first high-temperature-side heat exchanger, the above-described second low-temperature-side heat exchanger is cooled by the standing wave and the traveling wave,

or/and a standing wave and a traveling wave are generated through self excitation by cooling the above-described first low-temperature-side heat exchanger, and the above-described second high-temperature-side heat exchanger is heated by the standing wave and the traveling wave, and in the thermoacoustic apparatus, the above-described loop tube is configured to include a plurality of linear tube portions, which stand relative to the ground, and connection tube portions shorter than the linear tube portions, and the above-described first stack is disposed in the longest linear tube portion among the plurality of linear tube portions. Consequently, the surface wavefront of the acoustic wave generated in the first stack through self excitation can be stabilized in the long linear tube portion, and the standing wave and the traveling wave can be generated rapidly. Since the first stack is disposed in the standing linear tube portion, the time until the acoustic wave is generated can be reduced through the use of an updraft or a downdraft generated on the first stack side. Furthermore, after the acoustic wave is generated, the efficiency of heat exchange can be improved.

Best Mode for Carrying Out the Invention

[0035] A first embodiment of a thermoacoustic apparatus 1 according to an aspect of the present invention will be

described below with reference to drawings.

[0036] As shown in Fig. 1, the thermoacoustic apparatus 1 in the present embodiment includes a first stack 3a sandwiched between a first high-temperature-side heat exchanger 4 and a first low-temperature-side heat exchanger 5 and a second stack 3b sandwiched between a second high-temperature-side heat exchanger 6 and a second low-temperature-side heat exchanger 7 in the inside of a loop tube 2 configured to take on a rectangular shape as a whole. A standing wave and a traveling wave are generated through self excitation by heating the first high-temperature-side heat exchanger 4 on the first stack 3a side, and the second low-temperature-side heat exchanger 7 disposed on the second stack 3b side is cooled by propagating the standing wave and the traveling wave to the second stack 3b side.

[0037] In the present embodiment, in order to reduce the time from the heating of the first high-temperature-side heat exchanger 4 until the standing wave and the traveling wave are generated, a pair of linear tube portions 2a are disposed along the vertical direction (direction of gravity), connection tube portions 2b shorter than these linear tube portions 2a are disposed, and the first stack 3a is disposed in the lower portion of one of the linear tube portions 2a while being sandwiched between the first high-temperature-side heat exchanger 4 and the first low-temperature-side

heat exchanger 5.

[0038] The surface wavefront of the acoustic wave generated from the first stack 3a must be stabilized as rapid as possible in order to generate a standing wave and a traveling wave. However, if the length of the linear tube portion 2a, in which the first stack 3a is disposed, is small, the acoustic wave is reflected at corner portions 20b disposed both ends of the connection tube portion 2b, and the surface wavefront is disturbed due to phase inversion or the like. Therefore, in the present embodiment, the first stack 3a is disposed in the longest linear tube portion 2a in the loop tube 2 in order to stabilize the surface wavefront of the generated acoustic wave as rapid as possible. The length of this linear tube portion 2a is set to be longer than the length of the connection tube portion 2b, and when the length of the linear tube portion 2a is assumed to be La and the length of the connection tube portion 2b is assumed to be Lb,

[0039] La and Lb are set within the range satisfying

$$1:0.01 \leq La:Lb < 1:1.$$

However, it is preferable that the linear tube portion 2a is made as long as possible, and

[0040] La and Lb are set within the range satisfying

$$1:0.01 \leq La:Lb \leq 1:0.5.$$

[0041] On the other hand, the connection tube portion 2b

connecting the linear tube portions 2a is configured to have corner portions 20b at both ends. The acoustic wave propagated from the linear tube portion 2a is reflected by the corner portion 20b to the connection tube portion 2b. With respect to the configuration of the corner portion 20b, in order to reflect the acoustic wave efficiently to the connection tube portion 2b, a structure shown in Fig. 2 is used. Fig. 2 is a diagram showing a magnified corner portion 20b in the upper end portion of the linear tube portion 2a. Since configurations similar to the configuration of this corner portion 20b are used for the other corner portions 20b, explanations of the configuration of the corner portions 20b in other portions will not be provided. In Fig. 2, the corner portion 20b is configured to have an inner diameter substantially equal to the inner diameter of the linear tube portion 2a and have a diameter which is substantially equal to the inner diameter of the tube and which is centering the inside corner portion of the loop tube 2. In this manner, all the acoustic energy transferred from the linear tube portion 2a is reflected at the corner portion 20b, and is transferred to the connection tube portion 2b side without being returned to the linear tube portion 2a. Furthermore, the inner diameter of the corner portion 20b is configured to become substantially equal to that of the linear tube portion 2a and, thereby,

the inner walls of the linear tube portion 2a and the corner portion 20b can be made smooth. Consequently, the acoustic energy is prevented from being lost, so that the acoustic energy can be transferred efficiently. The shape of this corner portion 20b is not limited to an arch shape, and a linear shape as shown in Fig. 3 can also be used. Fig. 3 is a diagram showing a magnified corner portion 200b in the upper end portion of the linear tube portion 2a. In Fig. 3, the corner portion 200b is disposed in such a way that the outside corner portion thereof takes on a shape of a straight line which forms an angle of about 45 degrees with the linear tube portion 2a. Consequently, all the acoustic wave propagating in the linear tube portion 2a is reflected at this linear corner portion to the connection tube portion 2b side.

[0042] These linear tube portion 2a and connection tube portion 2b are composed of metal pipes. However, the material is not limited to the metal or the like, and may be transparent glass, a resin, or the like. When these portions are composed of a material, such as the transparent glass, the resin, or the like, positions of the first stack 3a and the second stack 3b can be checked and the status in the tube can easily be observed in an experiment or the like.

[0043] In the inside of the thus configured loop tube 2, the first stack 3a sandwiched between the first high-

temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5 and the second stack 3b sandwiched between the second high-temperature-side heat exchanger 6 and the second low-temperature-side heat exchanger 7 are disposed.

[0044] This first stack 3a is configured to take on a cylindrical shape which touches the inner wall of the loop tube 2, and is formed from a material, e.g., ceramic, sintered metal, gauze, or nonwoven metal fabric, which has a large heat capacity. The first stack 3a is configured to have multiple holes penetrating in the axis direction of the loop tube. As shown in Fig. 4 and Fig. 5, a stack 3c including a plurality of connection channels 30 arranged in such a way that the inner diameters of individual connection channels are increased one after another as the position of the connection channel approaches the outside from the center or a stack 3d including connection channels 30 arranged in such a way that the inner diameters of individual connection channels are decreased one after another as the position of the connection channel approaches the outside from the center can be used in place of this first stack 3a. Alternatively, as shown in Fig. 6 and Fig. 7, a stack 3e including meandering connection channels 30 (connection channel 30 indicated by a thick line) produced by laying, for example, a plurality of fine spherical

ceramic or a stack 3f including connection channels 30 arranged in such a way that the flow path lengths of individual connection channels are decreased one after another as the position of the connection channel approaches the inner perimeter surface of the loop tube 2 may be used.

[0045] Both the first high-temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5 are composed of a thin metal, and are configured to include through holes for transmitting the standing wave and the traveling wave in the inside thereof. Among these heat exchangers, the first high-temperature-side heat exchanger 4 is configured to be heated by an electric power supplied from the outside, waste heat, unused energy, or the like. On the other hand, the first low-temperature-side heat exchanger 5 is set at a temperature relatively lower than that of the first high-temperature-side heat exchanger 4 by circulating water around it.

[0046] The first stack 3a sandwiched between the first high-temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5, as described above, is disposed below the center of the linear tube portion 2a while the first high-temperature-side heat exchanger 4 is disposed on the upper side. The first stack 3a is disposed below the center of the linear tube portion 2a, as described above, on the grounds that an acoustic wave is generated

rapidly through the use of an updraft generated when the first high-temperature-side heat exchanger 4 is heated. The first high-temperature-side heat exchanger 4 is disposed on the upper side on the grounds that a warm working fluid generated when the first high-temperature-side heat exchanger 4 is heated is prevented from entering the first stack 3a and, thereby, a large temperature gradient is formed between the first low-temperature-side heat exchanger 5 and the first high-temperature-side heat exchanger 4.

[0047] With respect to the condition for the generation of the acoustic wave through self excitation in the first stack 3a, in the case where the working fluid flows in the first stack 3a, when a flow path radius of the parallel channels is assumed to be r, an angular frequency of the working fluid is assumed to be ω, a temperature diffusion coefficient is assumed to be α, and a temperature relaxation time is assumed to be τ ($= r^2/2\alpha$), the acoustic wave can be generated through self excitation most efficiently when $\omega\tau$ is within the range of 0.2 to 20. Therefore, r, ω, and τ are set in such a way as to satisfy these relationships. Furthermore, when one end of the linear tube portion 2a is connected to one end of the connection tube portion 2b in Fig. 2, an intersection of the respective center axes is assumed to be a start point X of a circuit, and an entire length of the circuit is assumed to be 1.00, the acoustic

wave can be generated through self excitation more rapidly and efficiently by setting the center of the first stack at a position corresponding to 0.28 ± 0.05 relative to the entire length of the circuit in a counterclockwise direction from the start point X.

[0048] On the other hand, similarly to the first stack 3a, the second stack 3b is configured to take on a cylindrical shape which touches the inner wall of the loop tube 2, and is formed from a material, e.g., ceramic, sintered metal, gauze, or nonwoven metal fabric, which has a large heat capacity. The second stack 3b is configured to have multiple holes penetrating in the axis direction of the loop tube. This second stack 3b is disposed in such a way that when a first peak of the pressure variation of the working fluid along the loop tube 2 is present in the vicinity of the first stack 3a, and a second peak is present at a position corresponding to about one-half the entire length of the circuit, the center of the second stack 3b is positioned past the second peak. As shown in Fig. 4 and Fig. 5, a stack 3c including a plurality of connection channels 30 arranged in such a way that the inner diameters of individual connection channels are increased one after another as the position of the connection channel approaches the outside from the center or a stack 3d including connection channels 30 arranged in such a way that the inner

diameters of individual connection channels are decreased one after another as the position of the connection channel approaches the outside from the center can be used in place of this second stack 3b similarly to that for the first stack 3a. Alternatively, as shown in Fig. 6 and Fig. 7, a stack 3e including meandering connection channels 30 (connection channel 30 indicated by a thick line) produced by laying, for example, a plurality of fine spherical ceramic or a stack 3f including connection channels 30 arranged in such a way that the flow path lengths of individual connection channels are decreased one after another as the position of the connection channel approaches the inner perimeter surface of the loop tube 2 may be used.

[0049] Likewise, both the second high-temperature-side heat exchanger 6 and the second low-temperature-side heat exchanger 7 disposed on the second stack 3b side are composed of a thin metal, and are configured to include through holes for transmitting the standing wave and the traveling wave in the inside thereof. Water is circulated around the second high-temperature-side heat exchanger 6 and, in addition, an object of cooling is connected to the second low-temperature-side heat exchanger 7. It is believed that the object of cooling is outside air, a heat-producing household electric appliance, a CPU of a personal computer, and the like. However, objects other than them may be

cooled.

[0050] An inert gas, e.g., helium or argon, is enclosed in the inside of the thus configured loop tube 2. This not limited to the above-described inert gas. A working fluid, e.g., nitrogen or air, may be enclosed. These working fluid is set at 0.1 MPa to 1.0 MPa.

[0051] When such a working fluid is enclosed, if helium or the like having a small Prandtl number and a small specific gravity is used, the time until an acoustic wave is generated can be reduced. However, if such a working fluid is used, the sound velocity is increased and the heat exchange with the stack inner wall cannot be performed smoothly. Conversely, if argon or the like having a large Prandtl number and a large specific gravity is used, the viscosity is increased and an acoustic wave cannot be generated rapidly. Consequently, it is preferable that a mixed gas of helium and argon is used. The above-described mixed gas is enclosed as described below.

[0052] First, helium having a small Prandtl number and a small specific gravity is enclosed in the loop tube 2, and an acoustic wave is generated rapidly. Subsequently, a gas, e.g., argon, having a large Prandtl number and a large specific gravity is injected in order to reduce the sound velocity of the acoustic wave generated. When this argon is blended, as shown in Fig. 8, a gas injection apparatus 9 is

disposed at the center portion of the connection tube portion 2b disposed on the upper side, and argon is injected therefrom. Argon is injected uniformly into the right and left linear tube portions 2a and, thereby, argon having a relatively large specific gravity is allowed to flow downward, so that the gas in the inside is made homogeneous. The procedure is not limited to the above-described case where helium is enclosed in advance and, thereafter, argon is injected. Conversely, argon may be enclosed in advance and, thereafter, helium may be injected. In this case, when the gas injection apparatus 9 is disposed at the center portion of the connection tube portion 2b disposed on the lower side, and helium is injected therefrom, helium having a relatively small specific gravity is allowed to move upward, so that the gas is made homogeneous. The pressures of these mixed gases are set at 0.01 MPa to 5 MPa, and in the case where the entire apparatus is miniaturized, the pressure is set at a relatively low level, for example, 0.01 MPa. In this manner, an influence of the viscosity in the miniaturized loop tube 2 can be reduced.

[0053] The operation state of the thus configured thermoacoustic apparatus 1 will be described below.

[0054] First, helium is enclosed in the loop tube 2. Under this condition, water is circulated around the first low-temperature-side heat exchanger 5 of the first stack 3a

and the second high-temperature-side heat exchanger 6 of the second stack 3b. When heat is applied to the first high-temperature-side heat exchanger 4 of the first stack 3a under this condition, a temperature gradient is generated in the first stack 3a due to the temperature difference between the first high-temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5, and the working fluid begins wandering minutely. Subsequently, this working fluid begins vibrating largely and circulates in the loop tube 2. At this time, since the linear tube portion 2a including the first stack 3a is set to be relatively long, the surface wavefront of the acoustic wave generated in the first stack 3a is stabilized, and a standing wave and a traveling wave can be generated in a short time in the loop tube 2. The acoustic energy due to the standing wave and the traveling wave is generated in the direction opposite to the transfer direction (direction from the first high-temperature-side heat exchanger 4 toward the first low-temperature-side heat exchanger 5) of the thermal energy in the first stack 3a, that is, in the direction from the first low-temperature-side heat exchanger 5 toward the first high-temperature-side heat exchanger 4, on the basis of the energy conservation law. The resulting acoustic energy is reflected efficiently at the corner portions 20b of the loop tube 2 and the like and, thereafter, is transferred to the

second stack 3b side. The working fluid is allowed to expand or shrink due to pressure variation and volume variation of the working fluid based on the standing wave and the traveling wave on the second stack 3b side. The thermal energy generated at that time is transferred in the direction opposite to the transfer direction of the acoustic energy, that is, from the second low-temperature-side heat exchanger 7 toward the second high-temperature-side heat exchanger 6 side. In this manner, the second low-temperature-side heat exchanger 7 is cooled and the intended object is cooled.

[0055] In the above-described thermoacoustic apparatus 1, the acoustic wave is generated through self excitation by the temperature gradient provided in the first stack 3a. However, in reality, it takes relatively long time until the above-described acoustic wave is generated through self excitation. On the other hand, it is possible to decrease the frequencies of the standing wave and the traveling wave by changing the diameter of the loop tube 2 in order to reduce the generation time of the standing wave and the traveling wave. However, this results in an insufficient output. In this case, as shown in Fig. 8, an acoustic wave generator 8 may be disposed.

[0056] This acoustic wave generator 8 is composed of a speaker, a piezoelectric element, or other devices which

forcedly vibrate the working fluid from the outside, and is disposed along the outer perimeter surface of the loop tube 2 or in the inside of the loop tube 2. It is preferable that the acoustic wave generator 8 is attached with a distance of one-half or one-quarter the wavelength of the standing wave and the traveling wave generated, and preferably, the acoustic wave generator 8 is disposed in such a way as to forcedly vibrate the working fluid in the axis direction of the loop tube 2 in correspondence with the movement direction of the standing wave and the traveling wave. As described above, when the acoustic wave generator 8 is disposed, the generation time of the standing wave and the traveling wave can be reduced, and the second low-temperature-side heat exchanger 7 can be cooled.

[0057] In the case where satisfactory cooling effect cannot be attained by the above-described thermoacoustic apparatus 1 alone, a thermoacoustic system 100, in which a plurality of thermoacoustic apparatuses 1 are connected, as shown in Fig. 9, may be used. In Fig. 9, reference numerals 1a, 1b··· and 1n denote thermoacoustic apparatuses 1 configured as described above, and these first thermoacoustic apparatus 1a, second thermoacoustic apparatus 1b··· and nth thermoacoustic apparatus 1n are disposed adjacently in series. All first high-temperature-side heat exchangers 4 in these first thermoacoustic apparatus 1a···

are heated by heaters or the like. On the other hand, respective second low-temperature-side heat exchangers 7 of thermoacoustic apparatus 1a··· are connected to first low-temperature-side heat exchangers 5 of thermoacoustic apparatus 1b··· adjacent thereto. In this manner, the temperature gradient in the second thermoacoustic apparatus 1b can be made larger than the temperature gradient of the first stack 3a in the first thermoacoustic apparatus 1a. Consequently, the temperature gradient of the thermoacoustic apparatus 1n can be increased one after another toward the downstream, and the last thermoacoustic apparatus 1n can output heat at a lower temperature. When the thermoacoustic apparatuses 1a··· are connected as described above, if each of the thermoacoustic apparatuses 1a··· is allowed to generate an acoustic wave through self excitation, it takes significantly much time until a standing wave and a traveling wave are generated in the last thermoacoustic apparatus 1n. Consequently, it is preferable that the time until a standing wave and a traveling wave are generated in each of the thermoacoustic apparatuses 1a··· is reduced by disposing acoustic wave generators 8, in particular, on the outer perimeter surface or in the inside of the loop tube 2.

[0058] In the above-described embodiment, the explanation is performed with reference to the thermoacoustic apparatus 1 in which the first stack 3a side is heated and the second

stack 3b side is cooled. Conversely, the first stack 3a side may be cooled and the second stack 3b side may be heated. Fig. 8 shows an example of this thermoacoustic apparatus 1.

[0059] In Fig. 10, the elements indicated by the same reference numerals as those in Fig. 1 to Fig. 8 are elements having the same structures as the elements set forth above. In Fig. 10, a first stack 3a is disposed above the center of a linear tube portion 2a, and a second stack 3b is disposed at an appropriate position in the linear tube portion 2a opposite thereto. With respect to the positions of installation of the first stack 3a and the second stack 3b, it is preferable that these are disposed at the positions at which the installation condition is the same as the condition in the above-described embodiment. Low-temperature heat at minus several tens of degrees or lower is input into the first low-temperature-side heat exchanger 5 and, in addition, an antifreeze liquid is circulated in a first high-temperature-side heat exchanger 4 and a second low-temperature-side heat exchanger 7. Consequently, an acoustic wave is generated through self excitation by the temperature gradient formed in the first stack 3a on the basis of the principle of thermoacoustic effect, the surface wavefront is stabilized in the linear tube portion 2a set to be relatively long, and a standing wave and a traveling wave

are generated rapidly through the use of a downdraft of the low-temperature heat. The acoustic energy of the standing wave and the traveling wave is generated in such a way that the movement direction thereof is a direction opposite to the transfer direction (direction from the first high-temperature-side heat exchanger 4 toward the first low-temperature-side heat exchanger 5) of the thermal energy in the first stack 3a. The acoustic energy due to the standing wave and the traveling wave is reflected efficiently at the corner portions 20b of the loop tube 2 and the like and, thereafter, is transferred to the second stack 3b side. The working fluid is allowed to repeat expansion and shrinkage due to pressure variation and volume variation of the working fluid based on the standing wave and the traveling wave on the second stack 3b side. The thermal energy generated at that time is transferred in the direction opposite to the transfer direction of the acoustic energy, that is, from the second low-temperature-side heat exchanger 7 toward the second high-temperature-side heat exchanger 6 side. In this manner, the second high-temperature-side heat exchanger 6 is heated.

[0060] In the present embodiment as well, in order to facilitate the generation of the standing wave and the traveling wave, an acoustic wave generator 8 may be disposed on the outer perimeter surface or in the inside of the loop

tube 2. Alternatively, the above-described thermoacoustic apparatuses 1 may be connected as shown in Fig. 9, and higher-temperature heat may be output from the thermoacoustic apparatus 1 on the end side.

[0061] According to the above-described embodiments, a pair of linear tube portions 2a having the same length are disposed along the vertical direction, connection tube portions 2b for connecting the linear tube portions 2a are disposed, and the linear tube portions 2b are set to be longer than the connection tube portions 2b. Under this condition, the first stack 3a sandwiched between the first high-temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5 is disposed in the linear tube portion 2a. Consequently, the surface wavefront of the acoustic wave generated through self excitation in the first stack 3a can be stabilized in the long linear tube portion 2a. Since the first stack 3a is disposed in the linear tube portion 2a along the vertical direction, the time until the acoustic wave is generated can be reduced through the use of an updraft or a downdraft generated on the first stack 3a side. Furthermore, after the acoustic wave is generated, the efficiency of heat exchange can be improved.

[0062] In the configuration of the above-described loop tube 2, when the length of the linear tube portion and the length of the connection tube portion are assumed to be La

and Lb, respectively, La and Lb are set within the range satisfying "1:0.01 ≤ La:Lb < 1:1", more preferably, La and Lb are set within the range satisfying "La:Lb ≤ 1:0.5". Therefore, the surface wavefront of the generated acoustic wave can be stabilized more rapidly.

[0063] In the above-described apparatus, in the case where the first stack 3a side is heated and the second stack 3b side is cooled, the first stack 3a is disposed below the center of the linear tube portion 2a. Therefore, a space for generation of an updraft due to the heat applied to the first high-temperature-side heat exchanger 4 can be ensured, and the standing wave and the traveling wave can be generated rapidly through the use of the updraft.

[0064] Conversely, in the case where the first stack 3a side is cooled and the second stack 3b side is heated, the first stack 3a is disposed above the center of the linear tube portion 2a. Therefore, a space for generation of a downdraft due to the low-temperature heat applied to the first low-temperature-side heat exchanger 5 can be ensured, and the standing wave and the traveling wave can be generated rapidly through the use of the downdraft.

[0065] In addition, when one end of the linear tube portion 2a is connected to one end of the connection tube portion 2b, an intersection of the respective center axes is assumed to be a start point of a circuit, and an entire

length of the circuit is assumed to be 1.00, the center of the first stack 3a is set at a position corresponding to 0.28 ± 0.05 relative to the entire length of the circuit. Consequently, the acoustic wave through self excitation can be generated more rapidly.

[0066] When an entire length of the circuit is assumed to be 1.00, a first peak of the pressure variation of a working fluid along the circuit is present in the vicinity of the first stack, and a second peak is present at a position corresponding to about one-half the entire length of the circuit, the second stack 3b is disposed in such a way that the center of the second stack 3b is positioned past the above-described second peak. Consequently, the cooling efficiency or the heating efficiency in the second stack 3b can be increased.

[0067] Since the acoustic wave generator 8 for generating the standing wave and the traveling wave is disposed on the outer perimeter portion or in the inside of the loop tube 2, the standing wave and the traveling wave can be generated more rapidly not only by the acoustic wave through self excitation, but also by forced vibration from the acoustic wave generator 8.

[0068] As shown in Fig. 4, the stack 3c including connection channels 30 arranged in such a way that the inner diameters of individual connection channels are increased

one after another as the position of the connection channel approaches the outside can also be used in place of the first stack 3a and the second stack 3b. Consequently, the inner diameters of the connection channels 30 in the vicinity of the boundary layer in the inside of the loop tube 2 can be increased, and the energy exchange in this portion can be performed efficiently.

[0069] As shown in Fig. 5, the stack 3d including connection channels 30 arranged in such a way that the inner diameters of individual connection channels are decreased one after another as the position of the connection channel approaches the outside, can also be used in place of the first stack 3a and the second stack 3b. Consequently, the inner diameters of the connection channels 30 in the center portion in the inside of the loop tube 2 can be increased, and the energy exchange in this portion can be performed efficiently.

[0070] Alternatively, as shown in Fig. 6, the stack 3e including meandering connection channels 30 can also be used in place of the first stack 3a and the second stack 3b. Consequently, large surface areas of the working fluid and the stack 3e can be ensured, the heat exchange with the working fluid is facilitated and, thereby, higher-temperature heat can be output.

[0071] Alternatively, as shown in Fig. 7, the stack 3f

including connection channels arranged in such a way that the flow path lengths of individual connection channels are decreased one after another as the position of the connection channel approaches the outside may be used in place of the first stack 3a and the second stack 3b. Consequently, the flow path lengths of connection channels close to the boundary layer of the loop tube 2 can be decreased, the speed gradient is made uniform as a whole and, thereby, the heat exchangers 4, 5, 6, and 7 can be uniformly heated or cooled altogether.

[0072] The material used for the first stack 3a and the second stack 3b is composed of at least one type of ceramic, sintered metal, gauze, and nonwoven metal fabric, and the $\omega\tau$ (ω: an angular frequency of the working fluid, τ: temperature relaxation time) thereof is set to become within the range of 0.2 to 20. Consequently, an acoustic wave can be generated through self excitation more rapidly and efficiently.

[0073] Furthermore, as shown in Fig. 9, a plurality of the above-described thermoacoustic apparatuses 1 are disposed, wherein a second low-temperature-side heat exchanger 7 in one thermoacoustic apparatus 1 is connected to a first low-temperature-side heat exchanger 5 in another thermoacoustic apparatus 1 adjacent thereto, or a second high-temperature-side heat exchanger 6 in one thermoacoustic

apparatus 1 is connected to a first high-temperature-side heat exchanger 4 in another thermoacoustic apparatus 1 adjacent thereto. Consequently, the temperature gradient in the first stack 3a can be increased one after another on an adjacent thermoacoustic apparatus 1 basis, higher-temperature heat or lower-temperature heat can be output from the thermoacoustic apparatus 1 on the end side.

[0074] The present invention is not limited to the above-described embodiments, and can be carried out in various forms.

[0075] For example, in the above-described embodiments, bilaterally symmetric loop tube 2 is disposed. However, not limited to this, and an irregularly meandering loop tube may be used. In this case, it is preferable that a first stack 3a serving as an acoustic wave generation source is disposed in the longest linear tube portion.

[0076] In the above-described embodiments, linear tube portions 2a along the vertical direction are disposed. However, not limited to this, and a linear tube portion slightly inclined relative to the ground may be disposed.

[0077] The positions of the above-described first stack 3a and the second stack 3b are not limited to the conditions set as described above, and they may be disposed at appropriately positions on the basis of various experiments or the like.

Brief Description of the Drawings

[0078] [Fig. 1] Fig. 1 is a schematic diagram of a thermoacoustic apparatus according to an embodiment of the present invention.

[Fig. 2] Fig. 2 is a diagram showing a magnified corner portion of a loop tube in the above-described embodiment.

[Fig. 3] Fig. 3 is a diagram showing the shape of a corner portion of a loop tube in another embodiment.

[Fig. 4] Fig. 4 is a diagram showing the shape of a stack in another embodiment.

[Fig. 5] Fig. 5 is a diagram showing the shape of a stack in another embodiment.

[Fig. 6] Fig. 6 is a diagram showing the shape of a stack in another embodiment.

[Fig. 7] Fig. 7 is a diagram showing the shape of a stack in another embodiment.

[Fig. 8] Fig. 8 is a schematic diagram of a thermoacoustic apparatus including an acoustic wave generator.

[Fig. 9] Fig. 9 is a schematic diagram of an acoustic heating system in which acoustic heating apparatuses are connected.

[Fig. 10] Fig. 10 is a schematic diagram of a thermoacoustic apparatus in another embodiment.

Reference Numerals

1··· thermoacoustic apparatus

2··· loop tube

2a··· linear tube portion

2b··· connection tube portion

20b··· corner portion

3a··· first stack

3b··· second stack

3c··· stack

3d··· stack

3e··· stack

3f··· stack

30··· connection channel

4··· first high-temperature-side heat exchanger

5··· first low-temperature-side heat exchanger

6··· second high-temperature-side heat exchanger

7··· second low-temperature-side heat exchanger

8··· acoustic wave generator

9··· gas injection apparatus

100··· thermoacoustic system